LES of Floating Wind Farms (Video Number V058)

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Abstract

The fluid dynamics video No.V058 is introduced, with brief descriptions of the numerical method used to generate the animation data, explanation of what is shown in the movies, and the main scientific findings obtained from this study.

Simulation approach

Offshore wind energy has become an important frontier of sustainable energy research. In this study, large-eddy simulation (LES) of wind turbulence coupled with potential-flow simulation of ocean waves is performed for floating wind farms for the first time. The LES of marine atmospheric boundary layer is performed on boundary-fitted grid that follows the wave motion. The nonlinear evolution of wavefield is simulated using a high-order spectral method. The wind and wave motions are coupled in the simulation by matching the kinematic and dynamic boundary conditions at the sea surface. Large wind farm is modeled as periodic wind turbine array, with the six-degrees-of-freedom motion of floating turbines solved subject to the wind and wave loads, and the effect of turbines on wind modeled using an actuator disc method. Details of the numerical methods and their validations are provided in Refs. [1-3].

Description of videos

The first and second animations show respectively the perspective and top views of the simulated ocean waves. The wavefield satisfies a JONSWAP spectrum, with peak wavelength of 52.3 m and significant wave height of 1.5 m. In the videos, the peak wave propagates from left to right with a phase speed of 9.0 m/s.

The third animation shows the coupled motions of wind turbulence and ocean waves. Sea surface and wind speed on two vertical planes are shown. The wind speed is normalized by its mean value at 1 km above the sea surface, which equals to 15.0 m/s in this case.

The last two animations show two cases of LES of floating wind farms. In addition to sea surface and wind speed, turbine wakes are illustrated with vorticity. The periodic wind turbine array consists of 3×3 turbines to represent part of a large wind farm. In the first case, the sea surface is covered by JONSWAP waves with parameters given above. In the second case, the JONSWAP waves are mixed with a swell with wave amplitude of 3.7 m and wavelength of 233.3 m. In the first and second cases, because the waves are respectively small and large, the turbine motions are weak and strong, respectively.

Main scientific findings

Analysis of the wind and wave statistics and turbine performance shows that: (i) For large floating wind farms, the energy extracted by the wind turbines is provided mainly by turbulence-mediated downward flux of kinetic energy from the atmosphere above, consistent with previous studies on land-based wind farms.[3] (ii) The wind field is substantially influenced by the waves due to the effect on sea surface roughness and wave-induced form drag. As a result, the energy extraction rate of the wind turbines is a function of wave conditions. (iii) The motion of floating turbines also affects the turbine performance. For future development of offshore wind farms, it is important to study the interaction among wind, waves, and turbine motions.

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